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Study of Subsurface Structural Trend and Stratigraphic Architecture Using Seismic Data A Case Study from Zindapir Inner Folded Zone, Sulaiman Sub-Basin, Pakistan

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Abstract: This study involves the interpretation of structural styles and stratigraphy of an area named Drazinda in Zindapir Inner Folded Zone, Sulaiman sub-basin based on the Seismic reflection data and well information. The seismic reflection method has advantage over other methods due to a greater penetration, higher resolution and accuracy. Depths to the reflecting interfaces are estimated from the recorded time and velocity information can be obtained from reflected signals.The detailed stratigraphiccorrelation and structural interpretationof approximately 44 kilometers has been carried out with the help of well data, formation tops and general stratigraphy of the area. Nine reflectors of different formations were marked on North-South seismic profile using the well tops of nearest wells Ramak-01 and Domanda-01 well and also based on the prominent reflection. The reflectors were named as 1. Litra, 2. Vehowa, 3. Chitarwata, 4. Drazinda, 5. Pirkoh, 6. Domanda,7. Habib Rahi, 8. Baska and 9. Ghazij Shale from top to bottom respectively. A syncline named as Drazinda Syncline has also been interpreted which lies North side of Domanda-01well. Values of Interval Velocity, Root Mean Square Velocity, Average Velocity and Mean Average Velocity for each Common Depth Point has been calulated and also were plotted.Finally time section was plotted for seismic profile. Interpretation of seismic data suggests that Tertiary Formations are present in the core of Drazinda Syncline while the Litra (Pliocene), Vehowa (Miocene) and Chitarwata (Oligocene) are exposed at the surface. On the South-Eastern part of the profile Domanda-01 well was drilled up to a depth of 3409 m and only Ghazij Formation encountered up to total depth.

Keywords: Drazinda Syncline, Sulaiman block, Interpretation andTime Section.

1. INTRODUCTION

Research area is the part of Zindapir Inner Folded Zone, Sulaiman Sub-Basin of Pakistan. The major tectonic zones of Sulaiman Sub-basin are SulaimanFoldbelt forming arc shape located in the west, SulaimanForedeep zone is also arc shaped located just in front of SulaimanFoldbelt and Southern Punjab Monocline located on the eastern part. Sulaiman Fold Belt is a major tectonic feature in the proximity of collision zone of Indo-Pakistan Plate with the Eurasian Plate and therefore contains a large number of disturbed anticlinal features (Kadri, 1995). Zindapir Inner Folded Zone is bounded in the east by Punjab Monocline, Sargodha is on the north, Sulaiman Fold belt is on the west and Sulaiman depression is its southern geological boundary. There are some large anticlines within Sulaiman belt and especially along the eastern margins due to Northward-striking of Indo-Pakistan plate. East Sulaiman structural play domain has narrow, straight anticlines as long as tens of kilometers with limbs that are broken locally by steeply dipping faults. Study of extension of these structures within the subsurface can be certainly conducted by the interpretation of seismic data. For this purpose a 2D seismic profile was collected from LMKR with the permission of DGPC.

Geological Setting

The Sulaiman Sub-basin along with other basins of Indo-Pakistan plate displays an enthralling array of features from the collision of Indo-Pakistan and Eurasian Plates (Powell, 1979). The breakup of Gondwana resulted in separation of Indo-Pakistan and African segments during Early Jurassic period and Indo-Pakistan Plate started moving towards North. In Paleocene- Eocene, Indo-Pakistan plate collided with the Eurasian Plate and from Oligocene and on ward under thrusting of Indo-Pakistan Plate beneath the Eurasian plate continues. The present day tectonic features of Sulaiman Sub-basin and its existing synclines, anticlines and faults came into existence during post-Cretaceous orogenic events. The Sulaiman Sub-basin is bounded on the east by the Indian Shield and on the west by the marginal Zone of the Indian plate. Zindapir Inner Folded Zone having an area of about 5,600 km^2 comprising North-South oriented fold system having four individual anticlines namely Dhodhak, Rhodho, Afib and Zinapir. The anticlines have narrow crests, steep eastern flanks and relatively gentle western limbs. Eocene rocks are exposed in the core of Dhodhak, Rodho and Afib and structures whereas Paleocene and upper most part of Cretaceous strata is exposed in the core of Zindapir anticline.

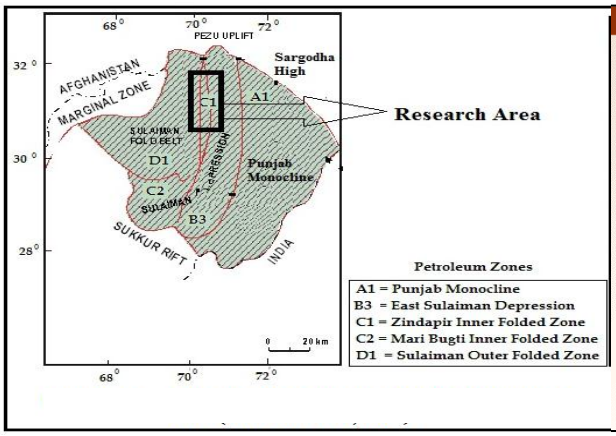
The seismic evidence shows some buried anticlines (e.g. Ramak) and synclines which may have been formed due to the flow of Eocene shales (Kadri, 1995). **(Fig. 1A and B).**

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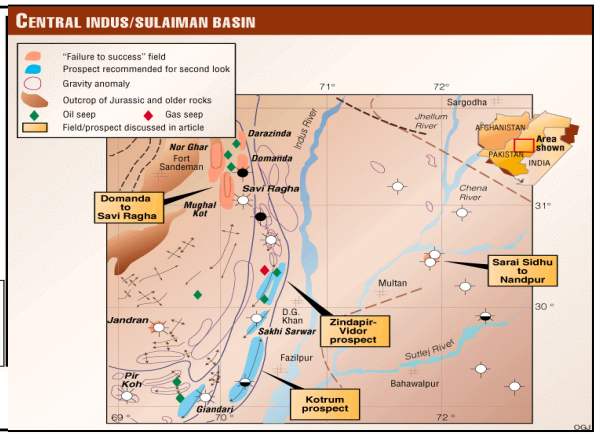


Figure No. 1 (A) Research area, a part of ZindaPir inner folded Zone (AfterRaza 1989)

Figure No. 1 (B) Location of Seismic line on Geological map

2. MATERIAL AND METHODS

Objectives of Study

The main objectives of research are as under:

1. Velocity analysis and preparation of Interval Velocity Plots, Root Mean Square Velocity Plots, Average Velocity Plots and MeanAverage Velocity graph at different Common Depth Points.

2. Preparation of time cross section of interpreted horizons and structures.

3. To study the structural trend of subsurface Structure and

4. To understand the stratigraphic architecture of study area.

3. PREVIOUS WORK

Some of related previous published concerning the structural styles, tectonics and geology of the area include: Nagappa (1959), Tainsh, stringer and Azad (1959), Williams (1959), Zuberi and Dubois (1962), Rahman (1963), Hunting Survey Corporation Limited (1961. An East-West cross-section showing continuation of Tertiary sediments of Drazinda syncline and domanda anticline was prepared by Hemphill and Kidwai(1973). Raza (1989) carried out work on Petroleum Prospects of Sulaiman Sub-basin. Kemal *et al.* (1991) consider East Sulaiman structural play of narrow straight anticlines as positive flower structure due to large scale distributive wrench faulting. Bannert and Raza (1992) assumed that basement was segmented into three different blocks during the collision of the Indo-Pakistan Plate. Three basement faults separated these blocks from each other and from the central part of the Indo-Pakistan Plate. The Khuzdar Block and the Sulaiman Blocks are separated by the Kirthar Basement Fault, the Sulaiman Block and the Hazara Block by the Sulaiman Basement Fault and the Hazara Block and main body of the Indo-Pakistan Plate to the east are separated by the Jhelum Basement Fault. Jadoon *et al.* (1994) interpreted the structures of the eastern and central SulaimanFoldbelt on the basis of surface geology and seismic analysis. Lillie *et al.* (1987), Humayun *et al.* (1991) and Jadoon *et al.* (1992) interpreted the presence of a basal decollement in pelitic rocks or fine carbonates above the crystalline basement at a depth of more than 11 km. Bannert *et al.* (1989), Bannert and Raza (1992), Bannert *et al.* (1995), Bender and Raza (1995), suggested that the oblique collision of the Eurasian and Indo-Pakistan plates caused the development of large scale, N-S running, left-lateral strike-slip faults in the basement which are responsible for the segmentation of the Indo-Pakistan Plate. Bender and Raza (1995)concluded that the Sulaiman range consists of a number of anticlines. The Sulaiman Anticlinorium, striking N-NE with separating synclines generally pass into vertical faults. The frontal part of Sulaiman fold belt is represented by a number of faults belonging to Domanda fault System. Iqbal and Helmcke (2004) suggested that the basement of Indo-Pakistan is involved in structural deformation of Zindapir Anticlinorium and its surroundings. Humayon *el al.* (1991) and data Lindsay *et al.* (2005)have evaluated the age span of the Chitarwata Formation in the ZindaPir Dome as Oligocene at its base and earliest Miocene at the contact with the Vehowa Formation. Malkani (2010), carried work on updated stratigraphy of Sulaiman sub-basin. Iqbal and Khan (2012) carried out work on Impact of Indo-Pakistan and Eurasian Plates Collision in the Sulaiman fold belt, Pakistan and suggested that the oblique collision of Indo-Pakistan and Eurasian plates led to the formation of Kirthar Sulaiman foldbelt. Adeel *et al.* (2013) recommended that subsurface structure pattern of Zindapir Anticlinorium may be investigated in detail using additional seismic data.

4. DATA SET AND METHODOLOGY

Two Dimensional Seismic Data and well tops were collected from LMK Resources by the permission of Directorate General of Petroleum Concessions (DGPC), Ministry of Petroleum and Natural Resources,

Islamabad. Interpretation of Seismic data involves conversion of velocity and time in to depth of subsurface reflecting interfaces to convert seismic data in to useful geological and structural image. The reflectors of different subsurface formations were marked with the help of well tops of Domanda-01 and Ramak-01**(Fig. 2).** Seismic stratigraphic analysis involves the interpretation of seismic section in to sequence of reflections that are interpreted as the seismic expression of genetically related sedimentary sequences whereas the structural interpretation is the analysis of subsurface structural styles. Analysis of the Seismic velocity is a complex parameter as it varies laterally as well as vertically due to the variation inphysical and geological conditions. Mean Average velocity values **(Table.1)** have been calculated from velocity window provided on the top of the seismic section. Finally mean average velocity graph, time sections and depth sections were prepared to betterunderstand the variation of seismic velocity within the subsurface.

5. PARAMETERS OF SEISMIC LINE

Name of the Seismic Line	Direction	Group Interval (meters)	Shot Point Interval (meters)	No of Channels	Record Length (milli-seconds)	Fold	Length Kilo Meters
812 DA-08	N-E	75	75	52	6000	26	44.33

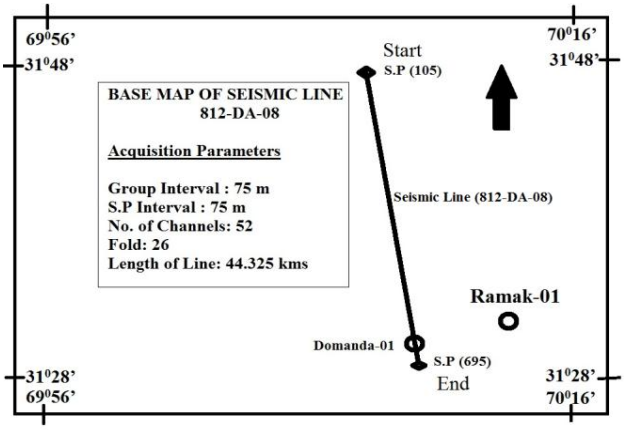


Fig. 2.Basemap showing Seismic Line, Domanda-01 and Ramak-01 wells

Well Information for Correlation

Well Details used for stratigraphic correlation are under:

Well Name: DOMANDA-01	**Type: EX**	**Status: ABD**
Operator: PPL	**Spud Date: 26/11/1959**	**Compl. Date: 23/04/1993**
Depth/m: 3408.4	**Latitude: 31 29 43.00**	**Longitude:70 11 58.00**
K.B.E: 723.00	**Province:K.P.K**	**Formation: GHAZIJ**

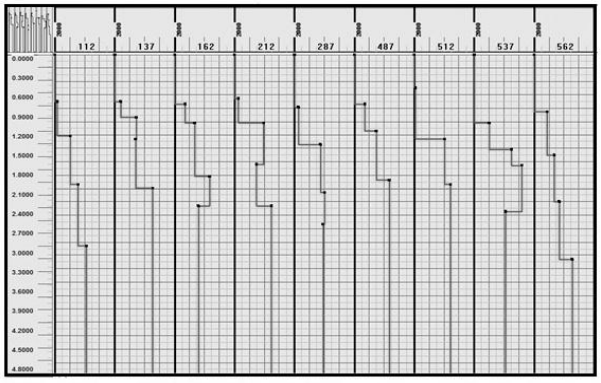
Well Name: RAMAK-01	**Type: EX**	**Status: ABD**
Operator:LASMO	**Spud Date: 10/02/1993**	**Compl. Date: 23/04/1993**
Depth/m: 4455.0	**Latitude: 31 22 40.00**	**Longitude:70 23 26.50**
K.B.E: 218.00	**Province:K.P.K**	**Formation: DRAZINDA**

Data Analysis and Interpretation

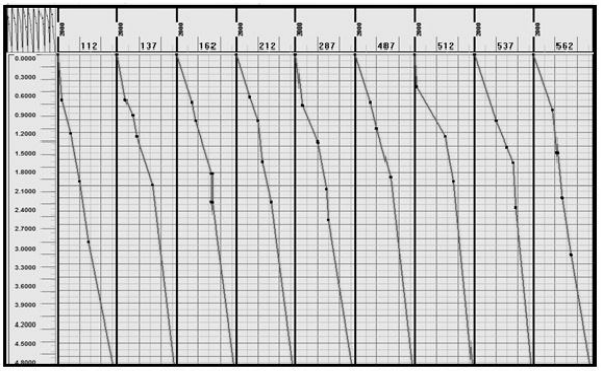
Seismic velocity vary significantly in sedimentary rocks as compared to igneous and metamorphic rocks. Metamorphic and igneous rocks have little or no porosity and the seismic wave velocity depend upon the elastic properties of the material itself. In terms of lithology, whenever there is a change in grain size and mineralogical composition of the rock, velocity behavior changes. An increase in grain size will result in the increase in velocity. Average velocity is simply the total distance travelled divided by the total time travelled. Values of root mean square velocity were calculated from interval velocity values given in velocity window, which were converted in to average velocity and plotted (**Fig. 3 A, B, C and D).** The average seismic velocity is the distance travelled by a seismic wave from the source location to some point divided by the recorded travel time. The Average velocity ranges from 2329 m/sec to 2407 m/sec for different Common Depth Points**.**

Time (m.Sec)	Mean Average Velocity (m/Sec)	Time (m.Sec)	Mean Average Velocity (m/Sec)	Time (m.Sec)	Mean Average Velocity (m/Sec)
0.0	2000	1.8	3277	3.6	3977
0.1	2073	1.9	3319	3.7	4019
0.2	2146	2	3357	3.8	4061
0.3	2219	2.1	3395	3.9	4103
0.4	2293	2.2	3431	4	4145
0.5	2366	2.3	3468	4.1	4187
0.6	2448	2.4	3505	4.2	4229
0.7	2530	2.5	3541	4.3	4269
0.8	2619	2.6	3579	4.4	4310
0.9	2711	2.7	3617	4.5	4350
1	2798	2.8	3655	4.6	4390
1.1	2876	2.9	3694	4.7	4431
1.2	2948	3	3734	4.8	4471
1.3	3016	3.1	3773	4.9	4512
1.4	3075	3.2	3813	5.o	4552
1.5	3128	3.3	3852		
1.6	3181	3.4	3893		
1.7	3232	3.5	3935		

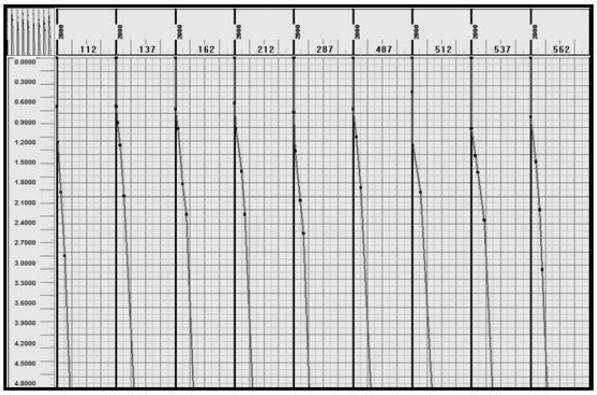
Table 1.Showing the calculated Mean Average Velocity values.



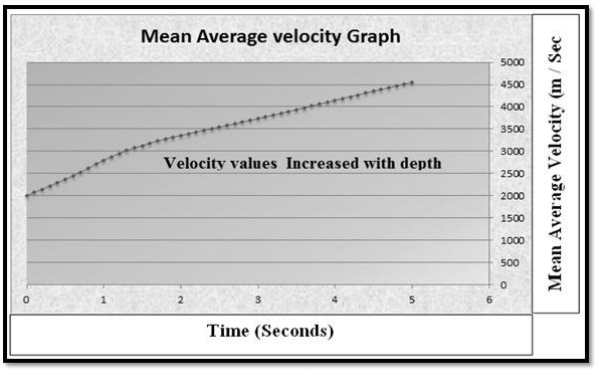
(A) Interval Velocity Plots at different common depth points



(B) Root Mean Square Velocity Plots at different common depth points



(C) Average Velocity Plots at different common depth points



(D) Mean Average Velocity graph

Fig.3:(A) Interval Velocity Plots at different common depth points **(B)** Root Mean Square Velocity Plots at different common depth points **(C)** Average Velocity Plots at different common depth points &**(D)** Mean Average Velocity graph.

6. RESULT AND DISCUSSION

Time Section

The transformation of seismic signal into litho-structural domain needs information of velocity and time. On seismic section, Root Mean Square velocities at selected shot points (SP) were provided which in turn were used to calculate interval velocities and then average velocities. The timesection has been prepared using the time and average velocity values.

Trend of Structural Style

Reflectors were picked and correlated with the help of well tops of Domanda-01 and Ramak-01 and a North-South cross-section of Drazinda syncline was prepared. The prominent structures present in the area are Drazinda Syncline**(Table-2).**

Table.2. Stratigraphy of Drazinda Area

Period	Epoch	Group	Formation	Top (m)	Bottom (m)	Thickness (m)
Tertiary	Recent	Alluvium		0	592	592
	Early Middle Pliocene	Vehowa	Litra	593	893	300
	Early Oligocene		Vehowa	894	1122	228
	Oligocene		Chitarwata	1123	1309	186
	Upper Eocene	Kahan	Drazinda	1310	1406	96
	Middle Eocene		Pirkoh	1407	1769	362
			Domanada	1770	2011	241
	Lower Eocene		Habib Rahi	2012	2249	237
		Baska		2250	2655	405
		Chamalang	Ghazij	2656	3409	753

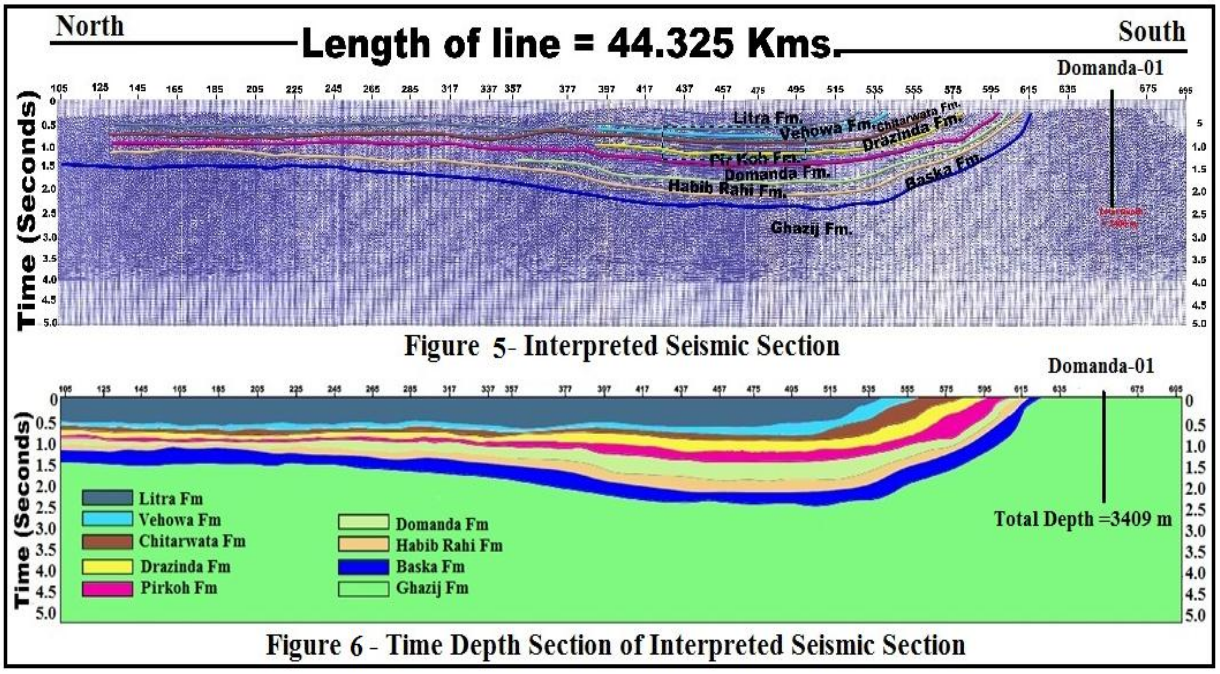


Figure 5- Interpreted Seismic Section

Figure 6 - Time Depth Section of Interpreted Seismic Section

Drazinda Syncline

The syncline starts immediately North side of the Domanda-01 well. The syncline has a steeper southern limb and thickened northern limb, which indicates the northwards flowage of shales. The core of Drazinda syncline is present under the SP 457 - SP 475. The diameter of synclinedecreases **(Fig. 5 and 6)**. Towards the North. The Inflection points of syncline for Litra, Vehowa, Chitarwata, Drazinda, Pirkoh, Domanda and Habib Rahi formations are Symmetric from SP 337 to SP 575. Time-depth section of seismic line suggests that Tertiary formations are present in the core of Drazinda Syncline. Litra (Pliocene), Vehowa (Miocene) and Chitarwata (Oligocene) are exposed at the surface. Drazinda and Pirkoh Formations (Eocene), underlay the Chitarwata formation. The flow of Drazinda Shales can be observed in the northern part. Domanda and Habib Rahi Formations are present below Pirkoh Limestone. Baska Shales underlying the Pirkoh Limestone have thickened in the northern limb of syncline due to the flowage. Most of the shale peculiar behavior is the flowage of Ghazij Shales along the Domanda Fault. Litra, Vehowa and Chitarwata formations are exposed at the surface between SP 285 – SP 585. The Average velocity ranges from 2256 m/sec to 2366 m/sec. Drazinda Formation and underlying Pirkoh Formation are exposed at the surface between SP 105 to SP 285 on the northern limb and SP 585 – SP 595 on the southern limb, which shows the thinning of limbs towards south. Drazinda Formation andPirkoh Formation have an average depth between 1310 to 1769 meters in the core of syncline. In Domanda Formation and Habib Rahi Formation velocity ranges from 2407 m/sec to 2488 m/sec. They are exposed at the surface between SP 595 to SP 615 on the southern limb. Habib Rahi Limestone attains a depth of 2249m in the core of syncline. Baska Shale is exposed between SP 615 to SP 635 at the southern limb of Drazinda syncline. In the core it has a depth of 3255 m. Baska Shale overlies theGhazij Formation. Fig, 5 and 6).

Stratigraphy: Complete stratigraphic correlation was carried out with the help of well tops of Domanda-01 and Ramak-01wells and the prominent reflectors of different horizons were picked. Total thickness of Alluvium is 590 meters. The stratigraphic information is as under.

Vehowa Group: The term "Vehowa Group" is used by Malkani (2009). Oligocene-Pliocene Vehowa Group is divided in to Litra, Vehowa and Chitarwata Formations and have a depth range from 893 to 1309 meters in the core of Drazinda Syncline.

Litra Formation: The Litra Formation was first used by Hemphill and Kidwai (1973). This formation consists of sandstone with subordinate shale and conglomerate. The sandstone is grey, thin to thick beded and massive, fine to coarse gained, gritty and calcareous. The shale is maroon, khaki and calcareous. Average thickness of Litra Formation in the core of syncline is 300 meters.

Vehowa Formation: The vehowa Formation was first used by Hemphill and Kidwai (1973). It consists of shale, sandstone and conglomerate. Shale is red, maroon, khaki and calcareous and ferruginous. Average thickness of Vehowa Formation in the core of syncline is 228 meters.

Chitarwata Formation: The Chitarwata Formation was first used by Hemphill and Kidwai (1973). It consists of sandstone, shale and conglomerate. Average thickness of Vehowa Formation in the core of syncline is 186 meters.

Kahan Group: The term Kahan group was first introduced by Khan (2009). Kahan group consists ofDrazinda, Pirkoh, Domanda, and Habib Rahi formations.

Drazinda Formation: Hemphill and Kidwai (1973) used the term Drazinda shale member. It consists of mainly shale/ mud and marl. The shale is choclate, khaki and calcareous. The average thickness of Drazinda Formation in the core of syncline is 96 meters.

Pirkoh Formation: White marl band of Eames (1952) has been referred Pirkoh Limestone by unpublished records of oil and gas exploration companies (Cheema, 1977). Pirkoh limestone member name was used by Hemphill and Kidwai (1973). It consists of limestone, marl and shale. The limestone and marl is milky white to cream white, thin to thick bedded. Its thickness in the core of syncline is 362 meters.

Domanda Formation: Hemphill and Kidwai (1973) used the term Drazinda shale member and designated the type section just west of Domanda post. It consists of mainly shale/ mudstone with one bed of gypsum. The shale is choclate, khaki and calcareous. The thickness of Domanda Formation is 241 meters in the core of Drazinda syncline.

Habib Rahi Formation: Tainsh, *et al,* (1959) used the term Habib Rahi limestone which is also mentioned by Hemphill and Kidwai (1973). It consists of limestone, shale and marl. The limestone and marl is cream white, thin to medium bedded. The thickness of Habib Rahi Formation in the core of syncline is 237 meters.

Baska Formation: The name Baskashale is proposed by the Hemphill and Kidawi (1973) to replace the descriptive term "shale with alabaster" of Eames (1952). It consists of gypsum, shale, limestone, marl and rare siltstone. The gypsum is gray to grayish white, medium to thick bedded and massive. The average thickness of Baska Formation is 405 meters.

Chamalang Group (Ghazij Formation): The term Chamalang Group was first used by Malkani (2010). The term Ghazij was introduced by Oldham (1890) and Williams (1959). The Ghazij Shale of Eocene age consists of green dark-grey and brown claystone. The claystone is carboniferous in places. The formation is considerably thinner to the south. Ghazij Formation was encountered up to depth of 3409 in the Domanda well.

7. CONCLUSIONS

Nine reflectors of different formations were marked on North-South seismic profile using the well tops of nearest wells Ramak-01 and Domanda-01 well and based on their prominent reflectivity, were named as 1. Litra, 2.Vehowa, 3.Chitarwata, 4.Drazinda, 5. Pirkoh, 6. Domanda, 7. Habib Rahi, 8. Baskaand 9. Ghazij Shale from top to bottom respectively. A syncline named as Drazinda Syncline has also been interpreted which lies north of the Domanda-01well. Values of Interval Velocity, Root Mean Square Velocity, Average Velocity and Mean Average Velocity for each Common Depth Point has been calculated and also were plotted. Interpretation of seismic data suggests that Tertiary Formations are present in the core of Drazinda Syncline while the Litra (Pliocene), Vehowa (Miocene) and Chitarwata (Oligocene) are exposed at the surface. On the South-Eastern part of the profile Domanda-01 well was drilled up to a depth of 3409 m and only Ghazij Formation encountered up to total depth.

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